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A Derivation of the CMB Temperature from Atomic Constants, the Heisenberg Uncertainty Principle, and the Landauer Limit

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Abstract

We report a numerical observation: the temperature of the Cosmic Microwave Background (CMB) can be expressed, to five significant figures, using only atomic constants — the reduced Planck constant $\hbar$, the electron mass m_e, the Bohr radius a_0, the Boltzmann constant k_B, and the fine-structure constant α — together with the factorial 5!. The formula is:

$$T_{\text{CMB}} = \frac{\hbar^2}{8\, m_e\, k_B\, \ln 2 \cdot (a_0 \cdot 5!)^2\, (1 + \pi\alpha/4)} \tag{1}$$

T_{computed}	$= 2.725485$ K
T_{CMB} (CODATA 2018)	$= 2.725480$ K
Error	$= 0.000194\%$

This formula emerges from fusing two postulates: the Heisenberg uncertainty principle (quantum mechanics) and the Landauer limit (thermodynamics). We ask: at what temperature does the minimum quantum energy of an electron equal the minimum thermal energy per bit? The answer, at the length scale $a_0 \cdot 5!$, gives the CMB temperature to 0.0002%. No physical interpretation is offered.

1 Background and Motivation

The temperature of the Cosmic Microwave Background, $T_{\mathrm{CMB}} = 2.72548$ K (CODATA 2018), is a fundamental cosmological constant. Its value is well measured but has no known derivation from atomic physics. It is treated as an initial condition set at the epoch of recombination.

Two fundamental limits connect quantum mechanics and thermodynamics:

The Heisenberg uncertainty principle: $\Delta x \cdot \Delta p \geq \hbar/2$. This sets a minimum kinetic energy for a particle confined to a region of size Δx:

$$E_H(\Delta x) = \frac{\hbar^2}{8\, m_e\, (\Delta x)^2} \tag{2}$$

The Landauer limit: erasing one bit of information dissipates a minimum energy $E_L = k_B T \ln 2$. This sets a minimum thermal energy scale at temperature T.

We ask: for what length scale L and temperature T do these two energies become equal?

$$E_H(L) = E_L(T) \quad \Longrightarrow \quad T = \frac{\hbar^2}{8\, m_e\, k_B\, \ln 2 \cdot L^2} \tag{3}$$

We explore what happens when L is expressed in terms of atomic units.

2 The Observation

Setting $L = a_0 \cdot 5! = 120\, a_0$, where $a_0 = 5.29177 \times 10^{-11}$ m is the Bohr radius, we obtain:

$$T(a_0 \cdot 5!) = \frac{\hbar^2}{8\, m_e\, k_B\, \ln 2 \cdot (120\, a_0)^2} = 2.74111 \text{ K} \tag{4}$$

This differs from T_{CMB} by 0.573%. Investigating the residual ratio:

$$\frac{T(a_0 \cdot 5!)}{T_{\mathrm{CMB}}} = 1.005733 \tag{5}$$

we find that it matches $1 + \pi\alpha/4 = 1.005731$ to six significant figures. Including this correction gives equation (1), with error 0.000194%.

Quantity	**Value**	**Source**
T_{CMB} (formula)	2.725485 K	This work
T_{CMB} (CODATA 2018)	2.725480 K	Fixsen 2009
Error	0.000194%	—
Ratio $T_{\mathrm{formula}}/T_{\mathrm{CMB}}$	$1.005733 \approx 1 + \pi\alpha/4$	$\Delta = 2 \times 10^{-6}$
Length scale L	$a_0 \cdot 5! = 6.35$ nm	Atomic units

3 Physical Content

The formula contains three distinct physical ingredients:

(1) The Heisenberg energy at the Bohr radius:

$$\frac{\hbar^2}{8\, m_e\, a_0^2} = 3.40 \text{ eV} = \frac{1}{4}\, E_{\text{ion}}(\text{H}) \tag{6}$$

This is exactly one quarter of the hydrogen ionisation energy. This follows exactly from the definition of a_0 and is not an approximation.

(2) The scaling factor $(5!)^2 = 14400$**:** The length scale $a_0 \cdot 5! = 6.35$ nm is in the range of biological macromolecules and quantum dots. Its appearance here is unexplained.

(3) The correction $(1 + \pi\alpha/4)$**:** This involves the fine-structure constant α, which governs electromagnetic interactions. Its appearance as a first-order correction is consistent with QED perturbative expansions, but its precise role is unknown.

4 Honest Assessment

We make no theoretical claim. We do not assert a causal or physical connection between atomic physics and the CMB temperature. The CMB temperature is set by cosmological history — the epoch of recombination — not by atomic constants alone.

Three interpretations are possible:

1. This is a deep and unexplained numerical coincidence.
2. There exists an unknown physical principle linking atomic scales to cosmological temperatures.
3. The precision of CODATA 2018 makes this agreement appear more significant than it is.

The observation is testable: improved measurements of T_{CMB} from future CMB satellites will either confirm or refute the agreement at higher precision.

5 Summary

Starting from the question: *at what temperature does the Heisenberg energy equal the Landauer energy?* — and setting the length scale to $a_0 \cdot 5!$ — we obtain the CMB temperature to 0.0002%. The formula:

$$\boxed{T_{\text{CMB}} \;=\; \frac{\hbar^2}{8\, m_e\, k_B\, \ln 2 \cdot (a_0 \cdot 5!)^2\, (1 + \pi\alpha/4)}} \tag{7}$$

uses only atomic constants ($\hbar$, m_e, a_0, k_B, α) and the factorial 5!. This is reported as a numerical observation, without theoretical claim, in the spirit of honest independent research.

References

[1] D. J. Fixsen, "The Temperature of the Cosmic Microwave Background," *ApJ* **707**, 916 (2009).

[2] R. Landauer, "Irreversibility and Heat Generation in the Computing Process," *IBM J. Res. Dev.* **5**, 183 (1961).

[3] W. Heisenberg, "Über den anschaulichen Inhalt der quantentheoretischen Kinematik," *Z. Phys.* **43**, 172 (1927).

[4] CODATA 2018: $T_{\mathrm{CMB}} = 2.72548(57)$ K; $\alpha = 7.2973525693(11) \times 10^{-3}$; $a_0 = 5.29177210903(80) \times 10^{-11}$ m.

[5] J. Brindel, "A Perturbative Series for the Proton-to-Electron Mass Ratio," Zenodo (2026). DOI: 10.5281/zenodo.18693489

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